AD-A095 347





CONTRACT REPORT ARBRL-CR-00441

# HYDRODYNAMIC CALCULATIONS WITH HULL, II

Prepared by

Science Applications, Inc.
2109 W. Clinton Avenue, Suite 800
Huntsville, AL 35805

December 1980

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

Approved for public release; distribution unlimited.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

| REPORT DOCUMENTATION PAGE | | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|---|
| 1. REPORT NUMBER<br>CONTRACT REPORT ARBRL-CR-00441 | 2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (and Subtitle)<br>Hydrodynamic Calculations with HULL, II | | 5. TYPE OF REPORT & PERIOD COVERED<br>Final; 2/12/79 - 12/18/79 |
| | | 6. PERFORMING ORG. REPORT NUMBER<br>SAI-80-792-HU |
| 7. AUTHOR(s)<br>Kenneth H. Dent<br>Henry T. Smith | | 8. CONTRACT OR GRANT NUMBER(s)<br>DAAK11-79-C-0039 |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Science Applications, Inc.<br>2109 W. Clinton Ave., Suite 800, Huntsville,AL35805 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>U.S. Army Armament Research and Development Command<br>U.S. Army Ballistic Research Laboratory<br>Aberdeen Proving Ground, MD 21005(ATTN: DRDAR-BL) | | 12. REPORT DATE<br>December 1980 |
| | | 13. NUMBER OF PAGES<br>36 |
| 14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) | | 15. SECURITY CLASS. (of this report)<br>UNCLASSIFIED |
| | | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

COR: George J. Klem, Ballistic Modeling Division

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

HULL
Hydrodynamics
Quartz Phenolic
Expanding Aluminum Sphere

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The HULL system of computer codes was used by SAI for technical analyses in support of BRL. An equation of state for quartz phenolic composite was added to HULL. Work was continued on the expanding aluminum sphere problem initiated in the previous contract period. A new approach was tried which resulted in more promising results than had previously been obtained.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

TABLE OF CONTENTS

## LIST OF FIGURES

# 1. INTRODUCTION

HULL is a collection of routines which uses finite differencing techniques to solve Lagrangian dynamics.[1] It is Eulerian in nature in that the mesh is not distorted in time. HULL is but one of several codes available in the scientific community which are being used to perform hydrodynamic calculations in support of technical analyses. Most of these codes were developed to analyze specific problems pertinent at the time instead of hydrodynamic problems in general. As the codes developed, they were expanded to handle different types of problems as the need for analysis in a particular area developed. HULL was originally designed to handle nuclear blast calculations. Later, strength of materials was added in order to do penetration mechanics. As a result of this pattern of growth and development, no hydrocode presently available is general in nature and can handle all types of problems equally well. Because of this, it is necessary to determine what types of problems a hydrocode can perform well and what its limitations are. Each hydrocode has its own advantages and disadvantages, and these need to be aired in order to make their results more acceptable to the scientific community.

It was the intent of SAI to provide assistance to BRL in the solution of hydrodynamic problems with HULL. The usefulness of HULL in providing support would be shown by comparison of its results to experimental data and the results from other hydrocodes.

A majority of this report deals with an unresolved problem in HULL discovered during the previous contract period. It was the intent of BRL to have SAI determine if HULL was capable of accurately modeling a rapidly expanding aluminum sphere. The problem set-up given by BRL to SAI is shown in Figure 1-1. It is a series of concentric aluminum shells with a velocity proportional to their radius, the maximum velocity being $5 \times 10^7$ cm/sec for the outer shell.

After the staff at SAI had executed the problem on HULL, it was determined that a serious defect was present in HULL. As the sphere began expanding, the edges of the sphere started to pull away from the left reflective boundary. The code acted as if the boundary were non-reflective, i.e., simulating the expansion of a hemisphere instead of a sphere.

The staff at SAI began a search for the cause of this problem and to see if a resolution could be effected. This search included discussions with other HULL and hydrocode users outside of SAI. By the end of the last contract period, the problem had not been isolated and no solution was found. During this present contract period, a much more promising technique for a solution to this problem with HULL was discovered. This technique, along with other problems investigated during the period, are described in the following pages.

---

[1] G.L. Purvis and H.T. Smith, "Hydrodynamic Calculations with HULL," Ballistic Research Laboratory Contract Report No. 00424, April 1980. AD B047871L

```
KEEL PROB=5.0 ATMCS=5 DT=1.E-15 ECS=6 HEADER
EXPANDING ALUMINUM SPHERE WITH REFLECTIVE BOTTOM BOUNDARY
NSTN=19
BREF=TRUE
IMAX=30 JMAX=30
NM=2 AIR=1 AL=2 GEOM=2 HOB=0.0
HOB=0.02
LREF=TRUE
MESH
NX=30 DX=1.0
NY=30 DY=1.0
GENERATE
AL
FIREIN CARDINPUT AL
         0.0      2.8E09            1.0      0.0
         0.5      2.8E09            1.0      0.179E7
         1.5      2.8E09            1.0      0.536E7
         2.5      2.8E09            1.0      0.893E7
         3.5      2.8E09            1.0      1.250E7
         4.5      2.8E09            1.0      1.607E7
         5.5      2.8E09            1.0      1.964E7
         6.5      2.8E09            1.0      2.321E7
         7.5      2.8E09            1.0      2.679E7
         8.5      2.8E09            1.0      3.036E7
         9.5      2.8E09            1.0      3.393E7
        10.5      2.8E09            1.0      3.750E7
        11.5      2.8E09            1.0      4.107E7
        12.5      2.8E09            1.0      4.464E7
        13.5      2.8E09            1.0      4.821E7
        14.0      2.8E09            1.0      5.000E7
                                                       1
CIRCLE RAD=14.0
STATIONS
XL=14.0     YL=2000.0
XL=13.9467 YL=2001.2202
XL=13.7873 YL=2002.4311
XL=13.5230 YL=2003.6235
XL=13.1557 YL=2004.7883
XL=12.6883 YL=2005.9167
XL=12.1244 YL=2007.0000
XL=11.4681 YL=2008.0301
XL=10.7246 YL=2008.9990
XL= 9.8995 YL=2009.8995
XL= 8.9990 YL=2010.7246
XL= 8.0301 YL=2011.4681
XL= 7.0000 YL=2012.1244
XL= 5.9167 YL=2012.6883
XL= 4.7883 YL=2013.1557
XL= 3.6235 YL=2013.5230
XL= 2.4311 YL=2013.7873
XL= 1.2202 YL=2013.9467
XL= 0.0    YL=2014.0
END
```

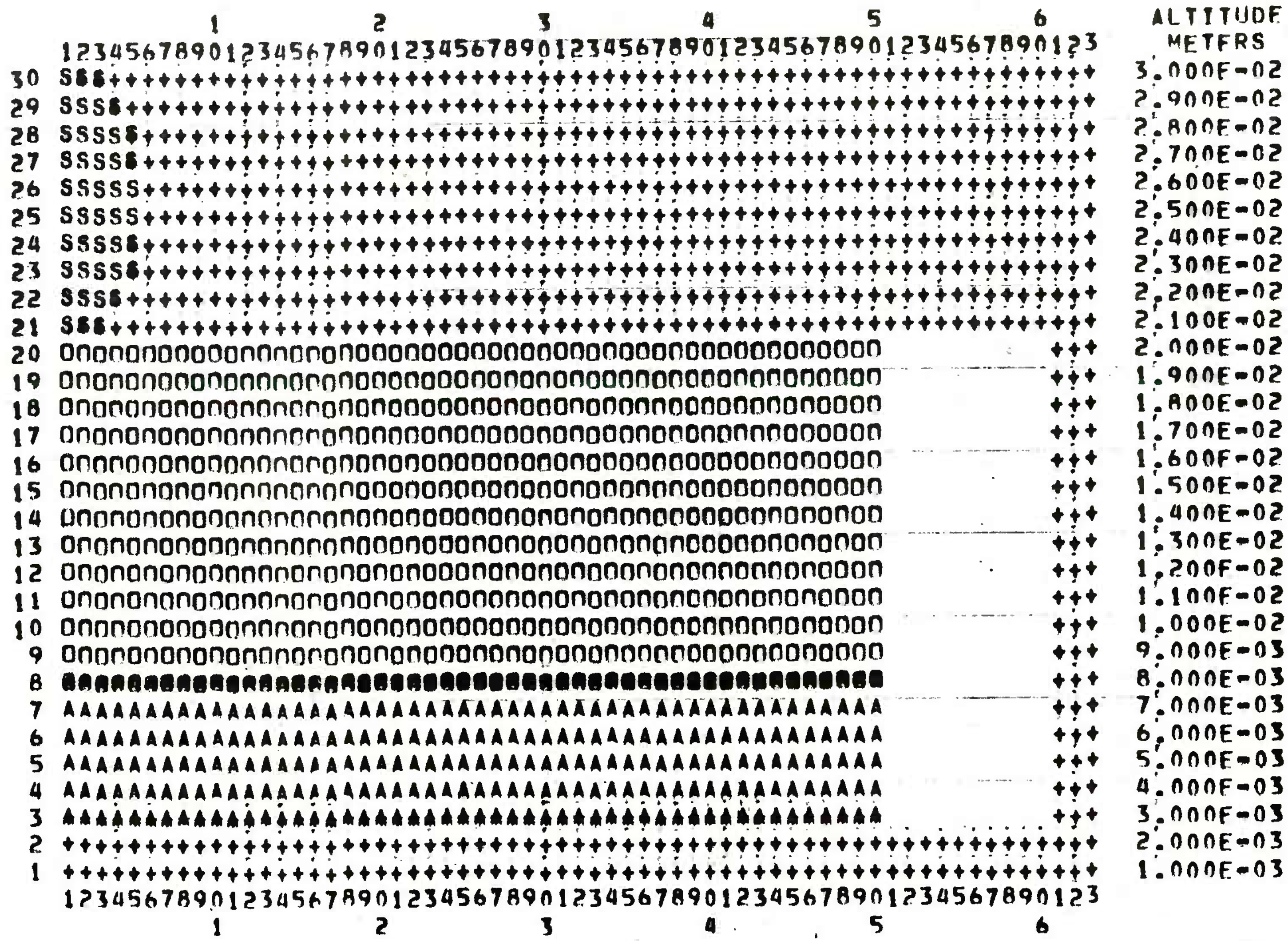
Figure 1-1. KEEL Input for Original Expanding Aluminum Sphere

## 2. EQUATION OF STATE FOR QUARTZ PHENOLIC MATERIAL

It was felt at SAI that to make HULL more usable in the field of ballistic missile defense, the library of materials contained in HULL should be able to describe a reentry vehicle as closely as practical. The metals available in HULL were sufficient, but there was no material available to be used as the ablative heatshield. To remedy this situation, an equation of state for quartz phenolic composite was obtained from J. Lacetera at BRL. This equation of state is a joined compressed and expanded Mie-Gruneisen equation used in BRLPUFF. This equation of state was modified so that it would give output necessary for the HULL system and was then incorporated into version 104. The equation and numerical constants of the material necessary for execution were added to HULL 104 CONVERT and catalogued under the name EOS ADDED TO HULL 104 CONVERT with the ID = SMCSAI. PLANK was recompiled with the name QPHEN given to the material so that a KEEL run would recognize it.

A value for the specific ambient internal energy of quartz phenolic composite could not be found. The only recourse was to make a careful estimate at what the value might be, because this is a necessary value for the execution of HULL. This estimate was changed several times until finally the equation of state stabilized. A test case for the quartz phenolic equation of state was devised in order to evaluate its usefulness. A 1-cm in diameter stone was impacted into a 1.15-cm layer of quartz phenolic with a 0.5-cm backing layer of aluminum at 3 km/sec. The mesh was set at 60 x 30 cells with each cell being 0.1 cm x 0.1 cm. The results of the problem are shown in Figures 2-1 through 2-6. The blank area shown in the figures is an immovable island placed in the mesh to prevent lateral flow of the quartz phenolic.

Figures 2-7a and 2-7b show the equation of state used and the jobstream necessary for its addition to HULL.



+ = Air
S = Stone
0 = Quartz Phenolic
A = Aluminum

Figure 2-1. Stone Collision with Quartz Phenolic at T = 0.0 sec.

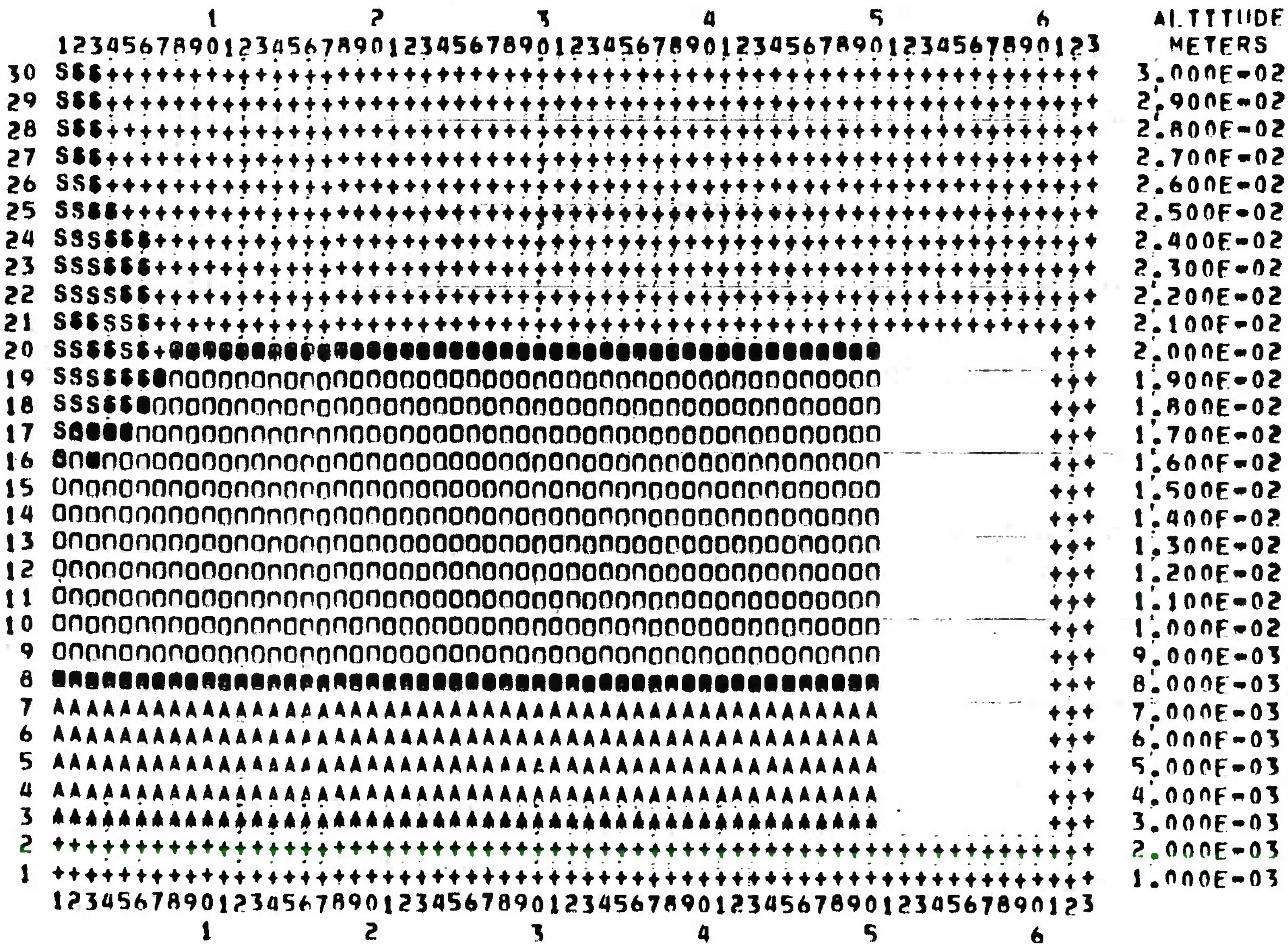



Figure 2-2. Stone Impact into Quartz Phenolic at $T = 2 \times 10^{-6}$ sec.

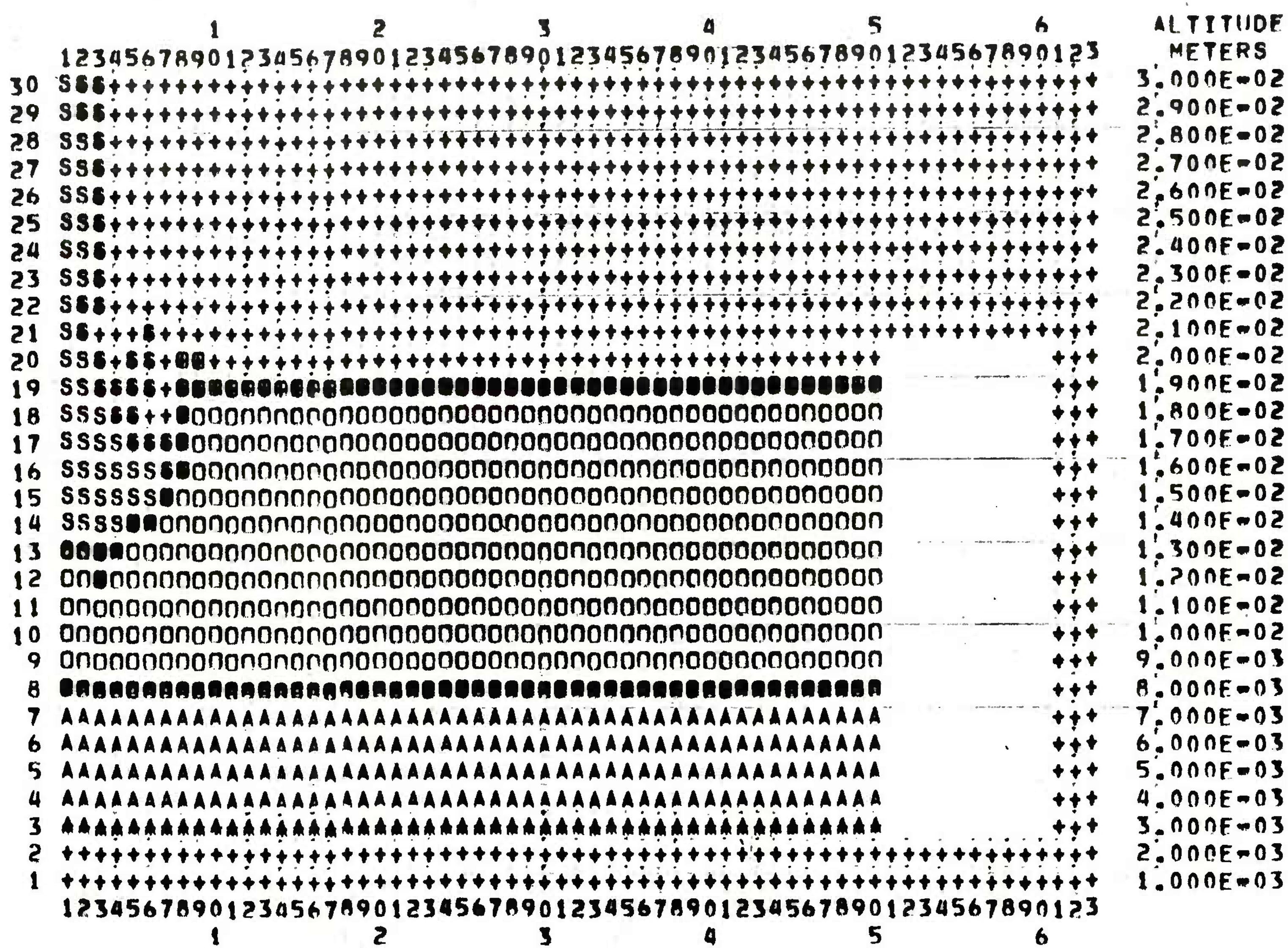



Figure 2-3. Stone Impact into Quartz Phenolic at T = 4.3 x $10^{-6}$ sec

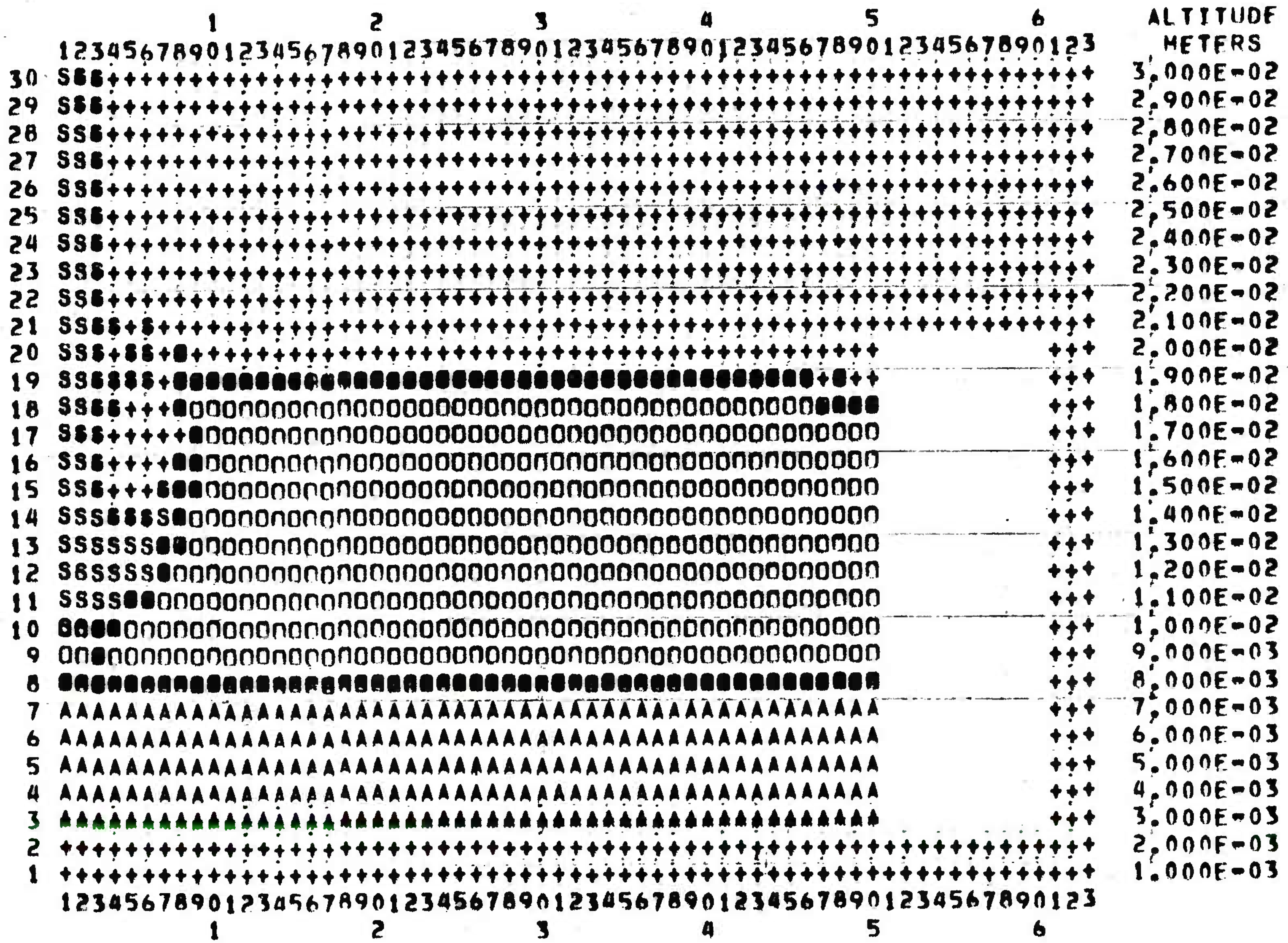



Figure 2-4. Stone Impact into Quartz Phenolic at $T = 6.3 \times 10^{-6}$ sec

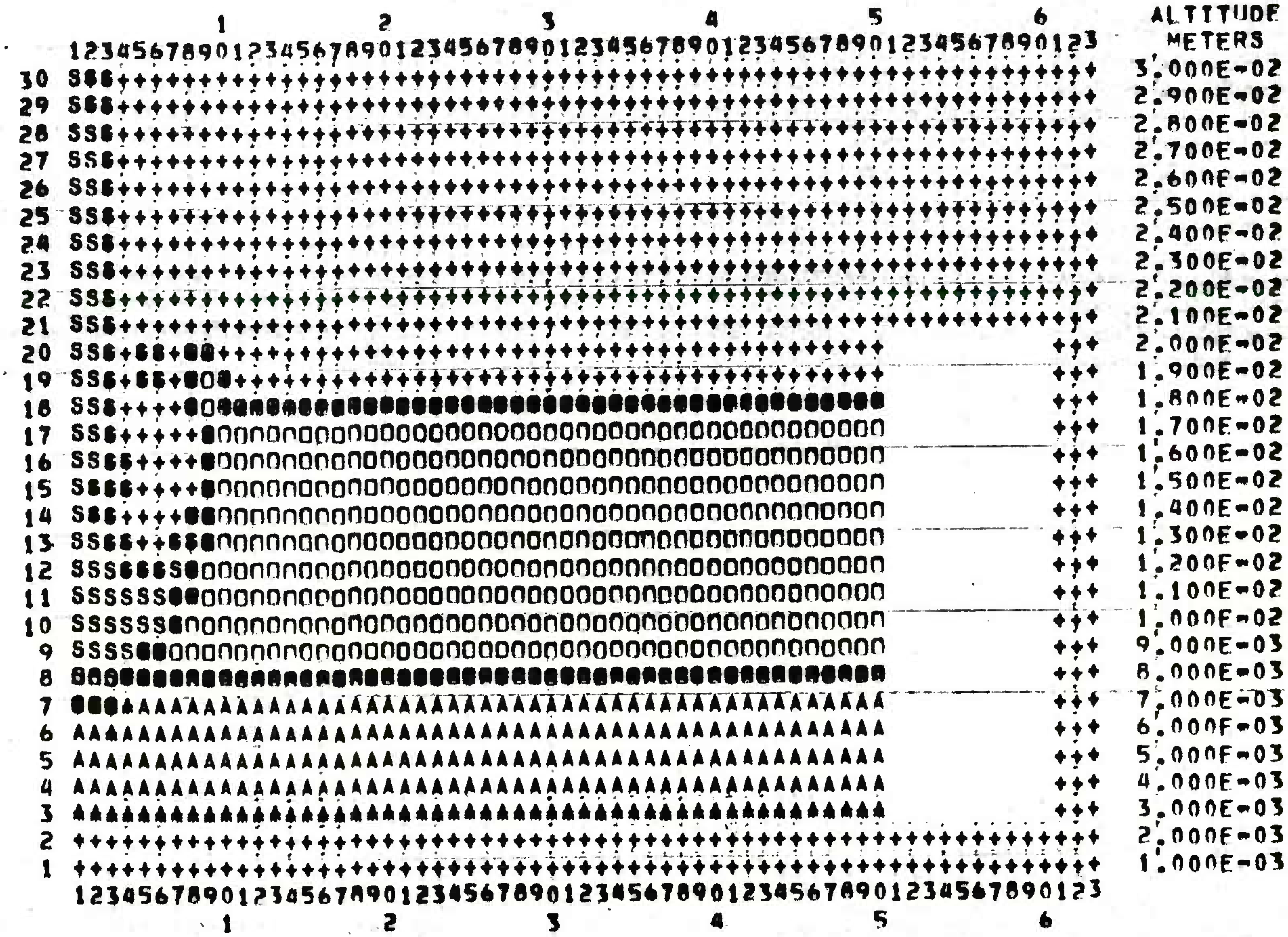



Figure 2-5. Stone Impact into Quartz Phenolic at T = 8 x $10^{-6}$ sec

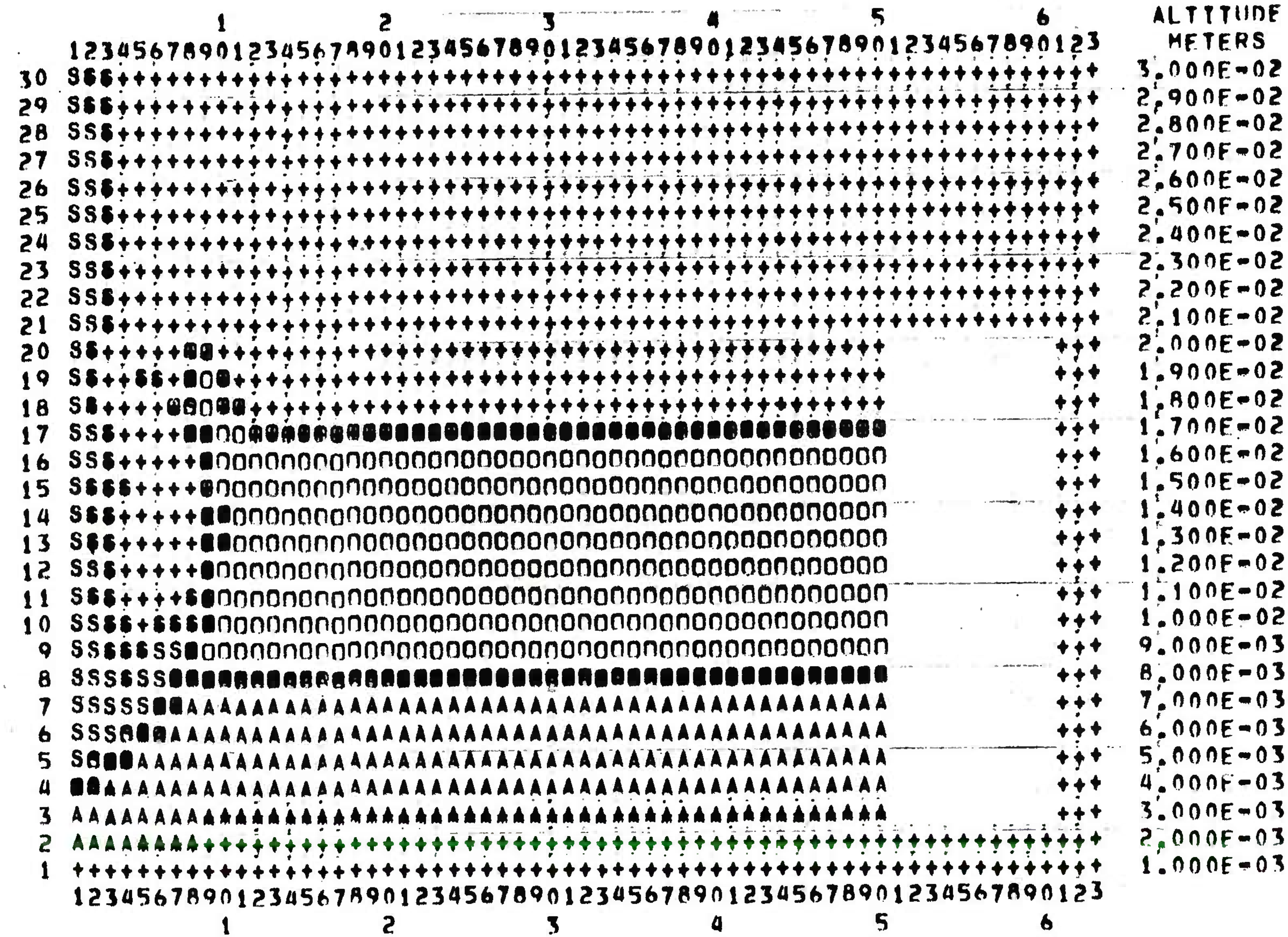



Figure 2-6. Stone Impact into Quartz Phenolic at T = 1.1 x $10^{-5}$ sec.

```
REQUEST,NEW,*PF.
ATTACH,OLD,HULL104CONVERT,ID=SMCSAI.
ATTACH,A,SAIL104LIB,ID=SMCSAI.
LIBRARY,A.
DYTHUL.
CATALOG,NEW,EOSADDEDTOHULL104CONVERT,ID=SMCSAI.
 X
SAIL UPDATE LIST VERSION 104
OPTIONS
SYS=76,VER=20,INST=5,ROUTE=0,ECS=1,FLUXER=1,
OBJLIB=1,DENSLIB=5,DENSHUL=5
ENDOPTIONS
*I 53945.
=
*PROC      QPHENCAL
     *       QPHEN(D,E,P,T)
*ENDPROC
*I 54074
*PROC      QPHENDAT
$      DATA RHOZ(QPHEN)/1.65/,AMBI(QPHEN)/2.E5/
$      DATA YLDST(QPHEN)/7.24E8/,RIGMOD(QPHEN)/1.104E11/
*ENDPROC
=
=
=
*I 55151
=
=
=
*PROC      QPHEN
       SUBROUTINE QPHEN(RHO,E,P,T)
       DIMENSION ESTCON(15), TEMP(10)
*INCLUDE EOS6COM
       DATA(ESTCON(I),I=1,15)/
     1  1.65,  0.29,  0.169,  0.063,  0.095,
     2   2.59E5,  0.0,  0.0,  0.0,  1.09E+11,
     3   0.0, 0.0, 0.0, 0.67, 3.24E-12/
       DTDE=8.54E-08
       ENU=RHO/ESTCON(1)
       RNU=ESTCON(1)/RHO
```

Figure 2-7a. Equation of State for Quartz Phenolic and Job Stream Necessary for Addition to HULL

```
      EMU=ENU=1.
      IF(ABS(EMU) .GE. 1.E-4) GO TO 10
      ENU=1.
      RNU=1.
      EMU=0.
10    IF(EMU .LT. 0.) GO TO 20
C     ***COMPRESSED MATERIAL - INTERMEDIATE QUANTITIES CALCULATED FOR
C     PRESSURE AND SOUND SPEED CALCULATIONS***
      TEMP(2)=EMU*(ESTCON(3)+EMU*(ESTCON(4)+EMU*ESTCON(5)))
      TEMP(3)=1.-.5*ESTCON(2)*EMU*RNU
      TEMP(6)=ESTCON(1)*ESTCON(2)
       TEMP(7)=TEMP(2)*TEMP(3)
      DPDRHO=ESTCON(1)*ESTCON(2)/RHO*E
     1+(1./ESTCON(1))*(ESTCON(3)+2.*ESTCON(4)
     2*EMU+3.*ESTCON(5)*EMU**2)*TEMP(3)
     3-ESTCON(2)/(2.*ESTCON(1))*TEMP(2)
      GO TO 30
C     *** EXPANDED MATERIAL - INTERMEDIATE QUANTITIES CALCULATED FOR
C         PRESSURE AND SOUND SPEED CALCULATIONS ***
20    TEMP(2)=SQRT(ENU)
      TEMP(3)=ESTCON(15)*(1.-RNU)*RNU
      TEMP(4)=EXP(TEMP(3))
      TEMP(6)=RHO*(ESTCON(14)+(ESTCON(2)-ESTCON(14))*TEMP(2))
      TEMP(7)=-TEMP(6)*ESTCON(10)*(1.-TEMP(4))
      DPDRHO=TEMP(6)/RHO*(E-ESTCON(10)*(1.-TEMP(4)))+
     1RHO*.5*(ESTCON(2)-ESTCON(14))*(ESTCON(1)/RHO)**0.5/ESTCON(1)*
     2(E-ESTCON(10)*(1.-TEMP(4)))+
     3TEMP(6)*ESTCON(10)*TEMP(4)*ESTCON(15)*(2.*ESTCON(1)**2/RHO**3-
     4ESTCON(1)/RHO**2)
C     *** PRESSURE AND SOUND SPEED CALCULATIONS ***
30    TEMP(10)=E
      P=TEMP(6)*TEMP(10)+TEMP(7)
      IF(DPDRHO .LE. 0.0) DPDRHO=ESTCON(6)**2
      DPDTAU=-(RHO**2)*(DPDRHO)
      T=(8.54E-08)*E
      RHOCSQ=RHO*DPDRHO
      RETURN
      END
*ENDPROC
 X
 W
```

Figure 2-7b. Equation of State for Quartz Phenolic and Job Stream Necessary for Addition to HULL (continued)

## 3. EXPANDING ALUMINUM SPHERE PROBLEM

A solution to this problem was initiated during the previous contract period, with unsuccessful results.[1] It involves the movement of a rapidly expanding aluminum sphere in a low density background. The problem was modeled as one-half of a sphere with a reflective left boundary, or one-fourth of a sphere with reflective left and bottom boundaries. HULL showed that as the calculation proceeded in time, the aluminum sphere separated from the boundaries, instead of intersecting them at $90^{0}$ as should occur. This implies that the calculation is not using truly reflective boundaries, but rather solving the problem of an expanding hemisphere or one-fourth quadrant of a sphere. It was suspected that this was a problem peculiar to verison 104, but it was determined by D. Matuska, one of the co-authors of HULL, that the problem lies in the diffusion limiter and was present in all versions of HULL. He also determined that it was a non-trivial problem to solve, and that it would take a significant level of effort to effect a solution.

With this information in mind, and knowing that there are often several methods of solving the same problem with HULL by changing the numerous input options, a search was begun for an alternate way of simulating the rapidly expanding aluminum sphere, which would minimize the boundary separation problem. The first attempt was to detonate a ball of high explosive inside of a hollow aluminum sphere. Several sizes, types of explosives and shell thicknesses were examined. Figures 3-1 and 3-2 show an example of these tests, a PBX sphere 38 cm in diameter surrounded with a 1-cm shell of aluminum. The results from these studies showed no boundary separation as had occurred with the original problem. This result was encouraging, but it was obvious that this type of system would never prove to be a viable substitute because the high-explosive detonation could not impart the necessary velocity to the aluminum shell. The next attempt was to use the nuclear blast simulation capability of HULL to achieve the pressures required to impart the necessary velocity to the aluminum sphere. To achieve a nuclear blast simulation, HULL requires as input the desired yield and position of the blast. From this it generates an isothermal sphere of air which has an internal energy equivalent to the yield of the bomb. The default value in HULL for the internal energy of air used in generating this sphere is $2 \times 10^{12}$ ergs/gram. At this specific energy, the radius of the sphere generated is much too large to be used for this problem, even with very low yields. To obtain a workable system, an internal energy of $1 \times 10^{16}$ ergs/gram was chosen. With this value and a yield of 0.02 kilotons, an isothermal sphere of air is generated with a radius of approximately 25 cm. For the simulation, this isothermal sphere is placed inside a sphere of aluminum with a radius of 35 cm and allowed to expand into an air background with a density of $1 \times 10^{-6}$ grams/cm$^{3}$. This background density was chosen to simulate a 50 km altitude burst. The mesh chosen for this problem was 50 x 200 cells, each cell being 1 cm x 1 cm. A graph of the density contours of the problem is shown in Figure 3-3. A feature peculiar to the generation of an isothermal sphere in HULL is that the problem time is not set to zero at the beginning of execution, but is set to some positive finite time at the beginning of the run. The reason for this is

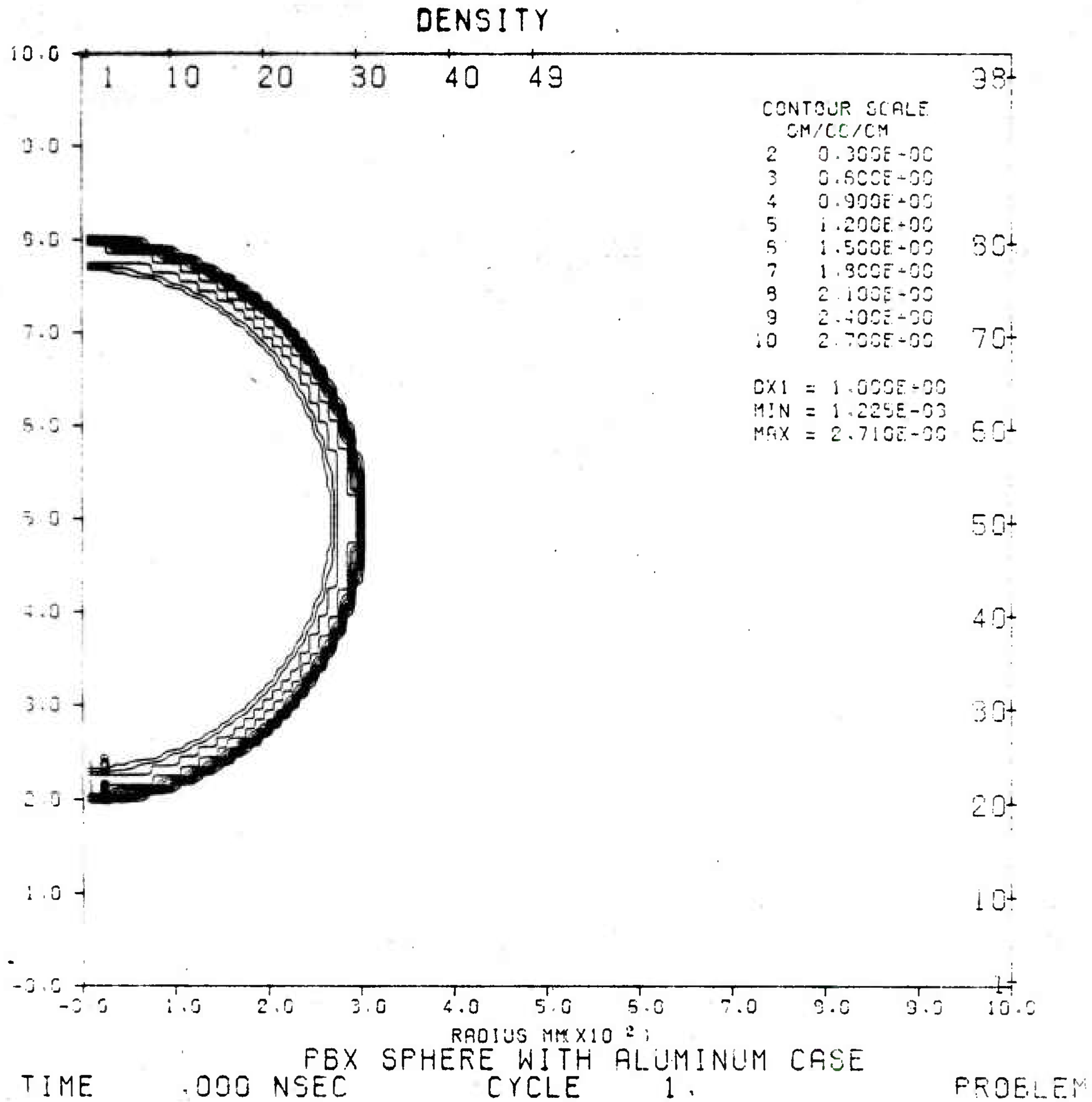



Figure 3-1. High Explosive Detonation at T = 1.17218 x $10^{-4}$ sec

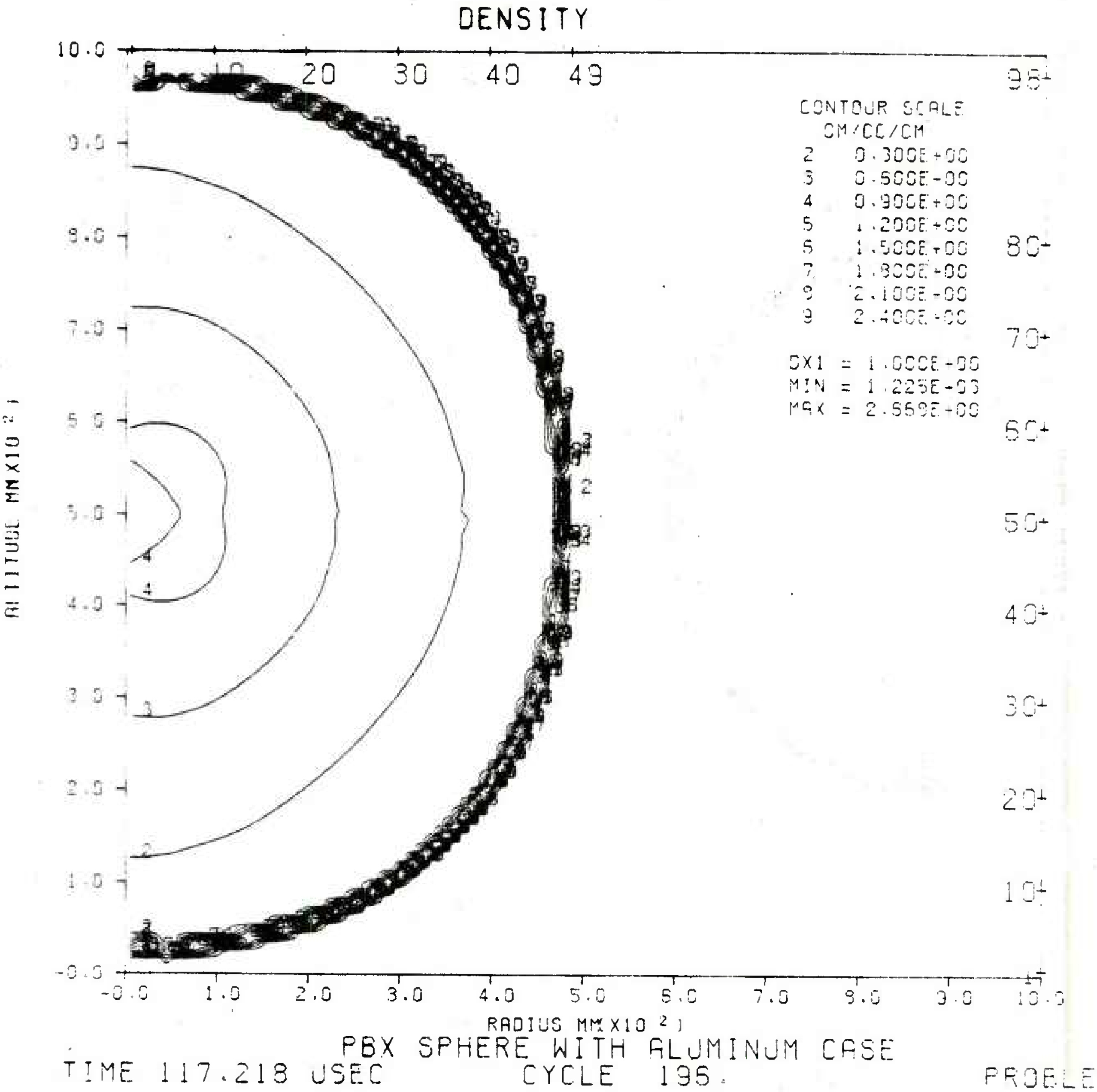



Figure 3-2. High Explosive Detonation at T = 1.17218 x $10^{-4}$ sec

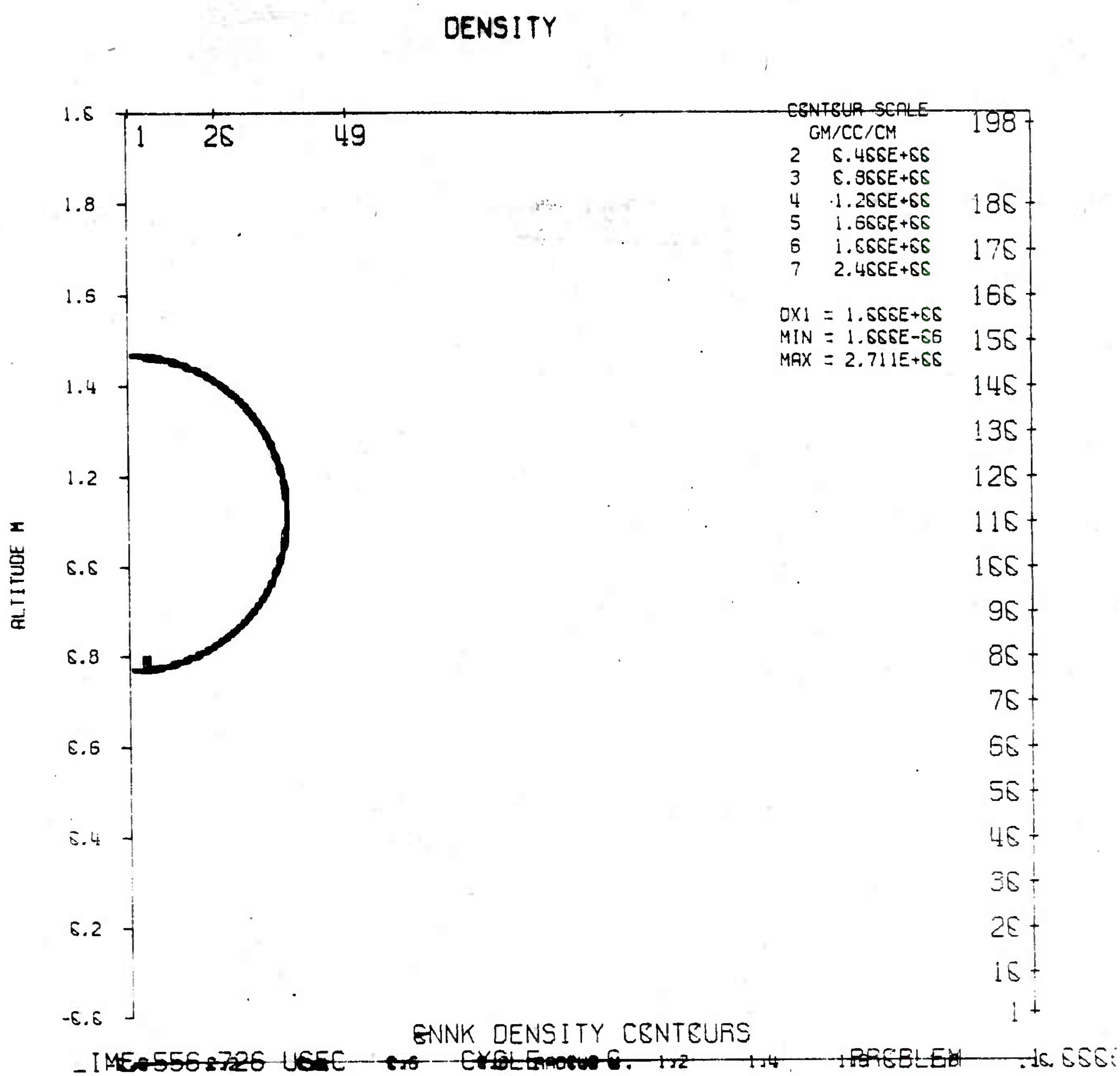



Figure 3-3. Density Contours for Expanding Aluminum Sphere at T = 0.0 sec.

not clear, but it is assumed that this may be the time required for the fireball of an actual bomb to reach the diameter generated by HULL. The starting time for this problem is $5.567 \times 10^{-4}$ seconds. The first HULL execution on this problem was done with a short computer time limit (150 octal seconds) to precipitate a fast turnaround to check for errors in the problem setup. The first picture obtained from the HULL run is at 1.2 μsec. This picture shows a maximum temperature of $4.666 \times 10^{5}$ degrees Kelvin and a maximum expansion velocity of $1.564 \times 10^{6}$ cm/sec. This compares with a maximum velocity of $5 \times 10^{7}$ cm/sec in the original aluminum sphere. From this point, the problem was run with a dump time interval of $2 \times 10^{-6}$ sec into the problem. At $21.6 \times 10^{-6}$ sec the maximum expansion velocity has increased to $2.310 \times 10^{6}$ cm/sec and the temperature has cooled to $6.633 \times 10^{4}$ degrees Kelvin. Notice in Figure 3-4 that the edge of the sphere has not separated from the boundary as in the previous aluminum sphere and that the edges appear to intersect the boundaries at 90 degrees, as they should . Also, note that the symmetry of the sphere has remained through time very well. At this point, the radius has increased to approximately 80 cm.

It was expected that the job would abort when the aluminium had expanded to the point at which a rezone would be attempted on the bottom boundary, as had occurred in the previous problem. The fact that previous problems had aborted when a rezone was attempted on the bottom boundary was due to an error in the rezoning routines which had not been resolved. But at $22.3 \times 10^{-6}$ sec into the problem, a successful rezone was performed on the bottom boundary. This had previously only been possible when the bottom boundary was made reflective. The reason for this is unknown. The only thing significantly different is the fact that an isothermal sphere is generated, and it is possible that the routines responsible for this perform some other function which allows a successful rezone at the bottom boundary.

This event unfortunately only occurred once. The rezone did not center the sphere properly in the mesh, leaving it closer to the bottom boundary than the top boundary. As time progressed, the aluminum sphere reached the bottom boundary before the top, and when this occurred, the program neither aborted or rezoned, but the aluminum sphere began flowing out of the mesh. Except for this, the aluminum sphere still is expanding as expected.

With this information, the decision was made to rerun this same problem with some changes in order to simulate the original problem more closely. The mesh was left at 50 x 200 cells, with each cell being 1 cm x 1 cm. The aluminum sphere was reduced from a radius of 35 cm to a radius of 25 cm. The yield of the isothermal sphere was increased from 0.02 kilotons to 0.05 kilotons. In order to keep the size of the isothermal sphere smaller than the aluminum sphere, the specific internal energy of the air used was increased to $1 \times 10^{17}$ ergs/gram. This resulted in a sphere with a radius of 3.44 cm.

The density of the background air was changed to $1 \times 10^{-9}$ grams/cm$^3$. This corresponds to an altitude of 95 km. The initial start time set by KEEL for the run was $7.9586 \times 10^{-4}$ sec. The dump time interval

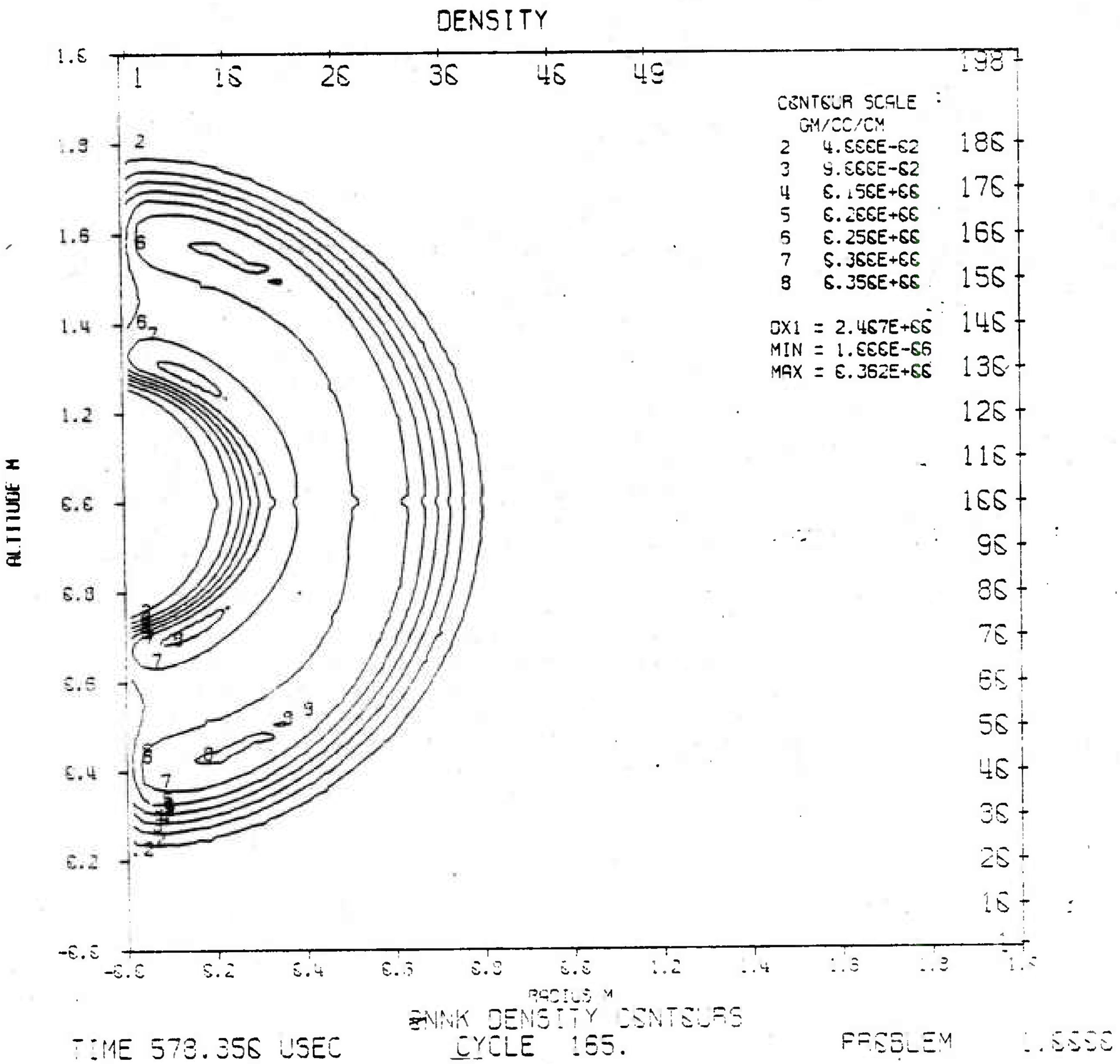



Figure 3-4. Density Contours of Expanding Aluminum Sphere at T = 21.6 x $10^{-6}$ sec.

was left at $2x10^{-6}$ sec. A graph of the density contours at start time is shown in Figure 3-5. The first picture dump given by the HULL exercise is $1.4 \times 10^{-7}$ sec into the problem. It shows a maximum temperature of $4.777x 10^6$ degrees Kelvin and a maximum expansion velocity of $5.474 \times 10^6$ cm/sec.

Figure 3-6 shows a graph of the density contours at $4.44x10^{-6}$ sec into the problem. The radius has expanded from 25 cm to 64 cm and the maximum expansion velocity has increased to $7.701x10^6$ cm/sec. The temperature has cooled to $1.100x10^6$ degrees Kelvin.

At $5.88x10^{-6}$ sec into the problem, an unexpected phenomena shows up. The surface of the sphere appears to be spalling. The material which is spalling is coming off the surface unsymmetrically, in chunk fashion. This material is moving only slightly faster than the surface of the sphere, less than 2%, but is two orders of magnitude lower in density. This large density difference may make the spalling insignificant. The surface of the sphere appears to have remained symmetrical. A plot of the density contours in this time is shown in Figure 3-7. The spalling is almost unnoticeable in this plot, showing only as a few dots above the surface of the sphere and as small spikes on the surface. A picture of the mesh created during the HULL run is shown in Figure 3-8. The spalling is much more obvious here.

As with the first problem, one successful rezone on the bottom boundary occurred. The sphere was again off-centered and eventually began flowing out of the mesh at the bottom boundary. This occurrence does not reduce the accuracy of the problem, and can be avoided by including a larger area in the original geometry. The effects of the rezone on the plotting routine are shown in Figure 3-9.

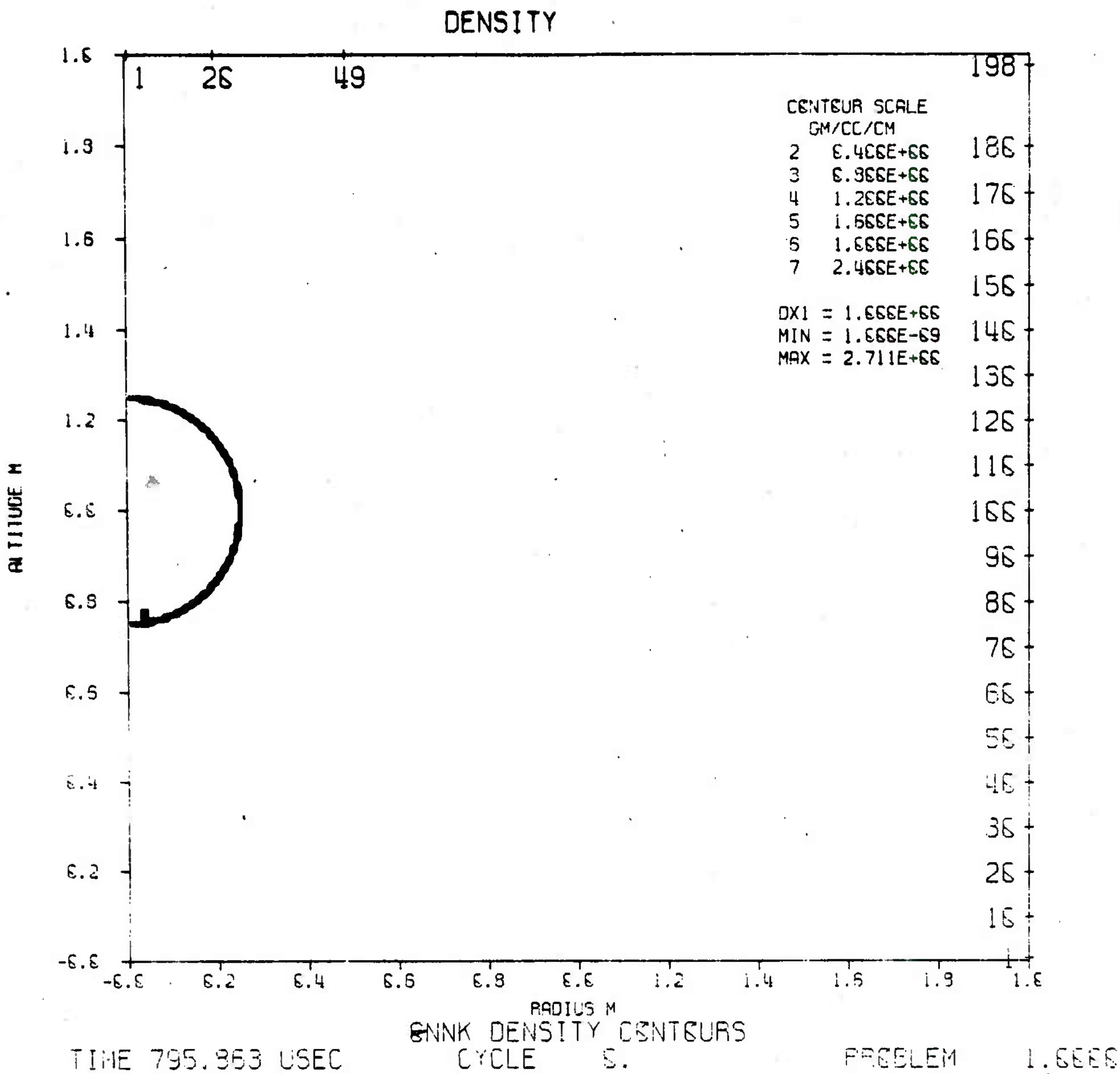



**Figure 3-5. Density Contours of Second Expanding Aluminum Sphere at T = 0.0 sec.**

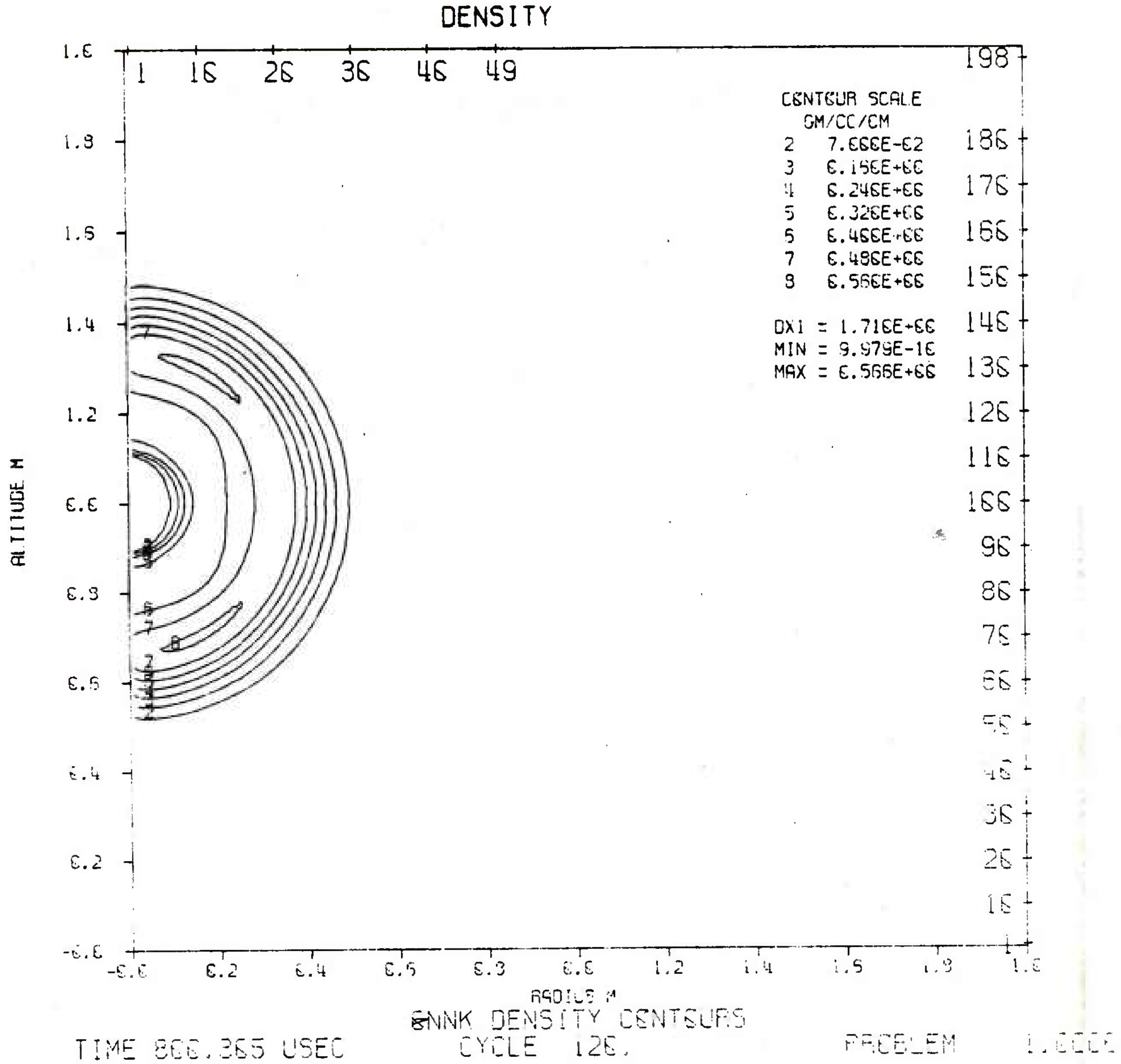



Figure 3-6. Density Contours of Second Expanding Sphere at T = 4.44 x $10^{-6}$ sec.

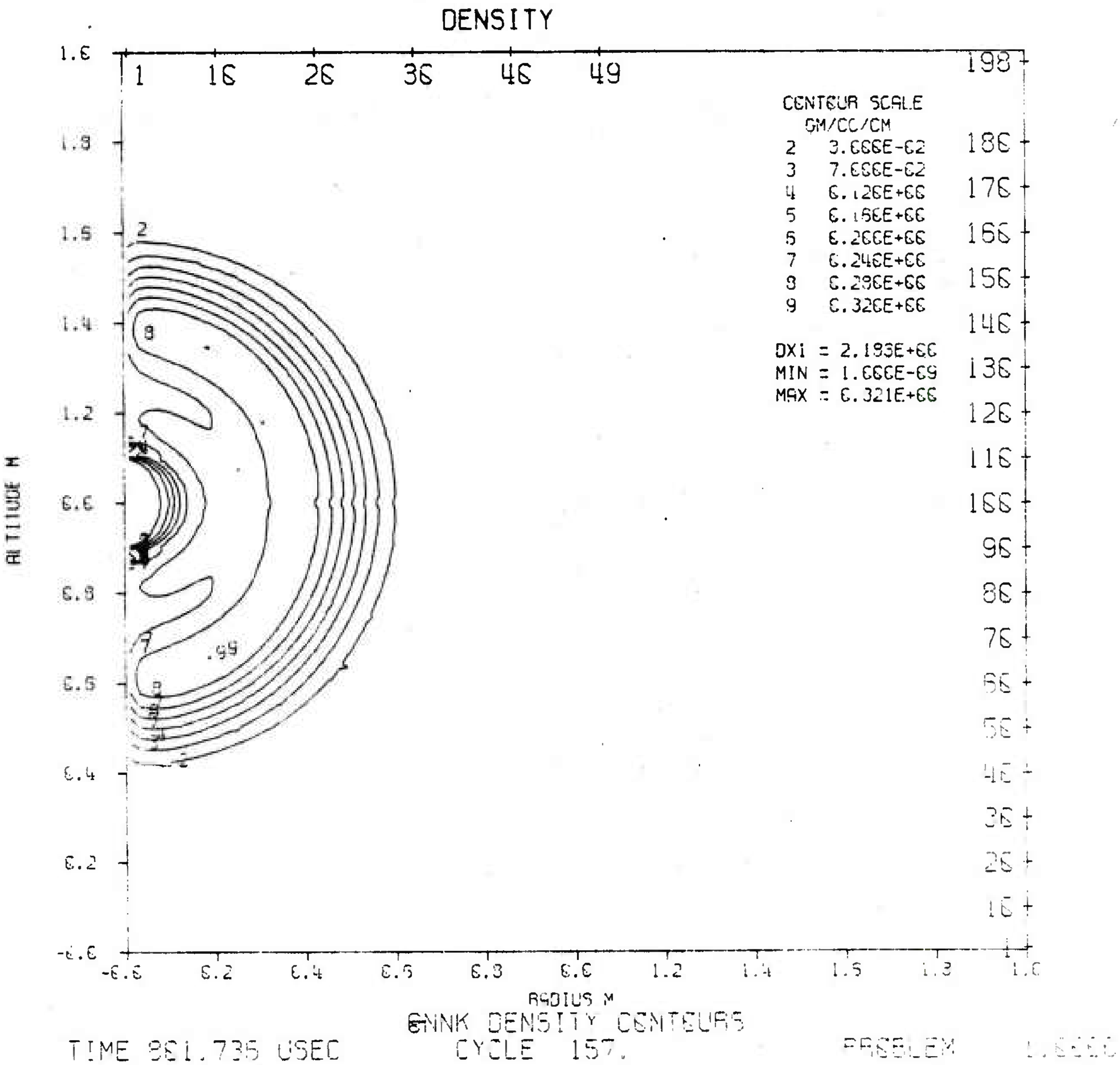



**Figure 3-7. Density Contours of Second Expanding Aluminum Sphere at T = 5.88 x $10^{-6}$ sec.**

```
             1         2         3         4         5    ALTITUDE
    12345678901234567890123456789012345678901234567890     METERS
200 ++++++++++++++++++++++++++++++++++++++++++++++++++    2.200E+00
199 ++++++++++++++++++++++++++++++++++++++++++++++++++    2.189E+00
198 ++++++++++++++++++++++++++++++++++++++++++++++++++    2.178E+00
197 ++++++++++++++++++++++++++++++++++++++++++++++++++    2.167E+00
196 ++++++++++++++++++++++++++++++++++++++++++++++++++    2.156E+00
195 ++++++++++++++++++++++++++++++++++++++++++++++++++    2.145E+00
194 ++++++++++++++++++++++++++++++++++++++++++++++++++    2.134E+00
193 ++++++++++++++++++++++++++++++++++++++++++++++++++    2.123E+00
192 ++++++++++++++++++++++++++++++++++++++++++++++++++    2.112E+00
191 ++++++++++++++++++++++++++++++++++++++++++++++++++    2.101E+00
190 ++++++++++++++++++++++++++++++++++++++++++++++++++    2.090E+00
189 ++++++++++++++++++++++++++++++++++++++++++++++++++    2.079E+00
188 ++++++++++++++++++++++++++++++++++++++++++++++++++    2.068E+00
187 ++++++++++++++++++++++++++++++++++++++++++++++++++    2.057E+00
186 ++++++++++++++++++++++++++++++++++++++++++++++++++    2.046E+00
185 ++++++++++++++++++++++++++++++++++++++++++++++++++    2.035E+00
184 XXX+++++++++++++++++++++++++++++++++++++++++++++++    2.024E+00
183 +XXXXX++++++++++++++++++++++++++++++++++++++++++++    2.013E+00
182 ++++XXX++XXXX+++++++++++++++++++++++++++++++++++++    2.002E+00
181 ++++++XXXXXXXXX+++++++++++++++++++++++++++++++++++    1.991E+00
180 ++++++XXX+++++XXX+++++++++++++++++++++++++++++++++    1.980E+00
179 XXXX+XXX++++++++XXX+++++++++++++++++++++++++++++++    1.969E+00
178 XXXXXX++++++++++++X+++++++++++++++++++++++++++++++    1.958E+00
177 XXXXXX+++++++++++XX+++++++++++++++++++++++++++++++    1.947E+00
176 XXXXXXX+++++++++++XX++++++++++++++++++++++++++++++    1.936E+00
175 XXXXXXXX+++++XXX+++X++++++++++++++++++++++++++++++    1.925E+00
174 XXXXXXXXX+++XXXXX++X++++++++++++++++++++++++++++++    1.914E+00
173 XXXXXXXXX++++XXXXX++++++++++++++++++++++++++++++++    1.903E+00
172 XXXXXXXXXX+++XXXXXX+++++++++++++++++++++++++++++++    1.892E+00
171 XXXXXXXXXXX+++XXXXXX++++++++++++++++++++++++++++++    1.881E+00
170 XXXXXXXXXXX+++XXX++XXX++++++++++++++++++++++++++++    1.870E+00
169 XXXXXXXXXXXX++XXXXX++X++++++++++++++++++++++++++++    1.859E+00
168 XXXXXXXXXXXX++XX++X+++++++++++++++++++++++++++++++    1.848E+00
167 XXXXXXXXXXXXX++XX+++++++++++++++++++++++++++++++++    1.837E+00
166 XXXXXXXXXXXXX++XX+++++++++++++++++++++++++++++++++    1.826E+00
165 XXXXXXXXXXXXXX++XX++++++++++++++++++++++++++++++++    1.815E+00
164 XXXXXXXXXXXXXX++XXX+++++++++++++++++++++++++++++++    1.804E+00
163 XXXXXXXXXXXXXXX++XXX++++++++++++++++++++++++++++++    1.793E+00
```

+ = Air

X = Aluminum

Figure 3-8. Upper Quadrant of Mesh Plot of Second Expanding Aluminum Sphere Created During HULL Execution at T = 5.88 x $10^{-6}$ sec.

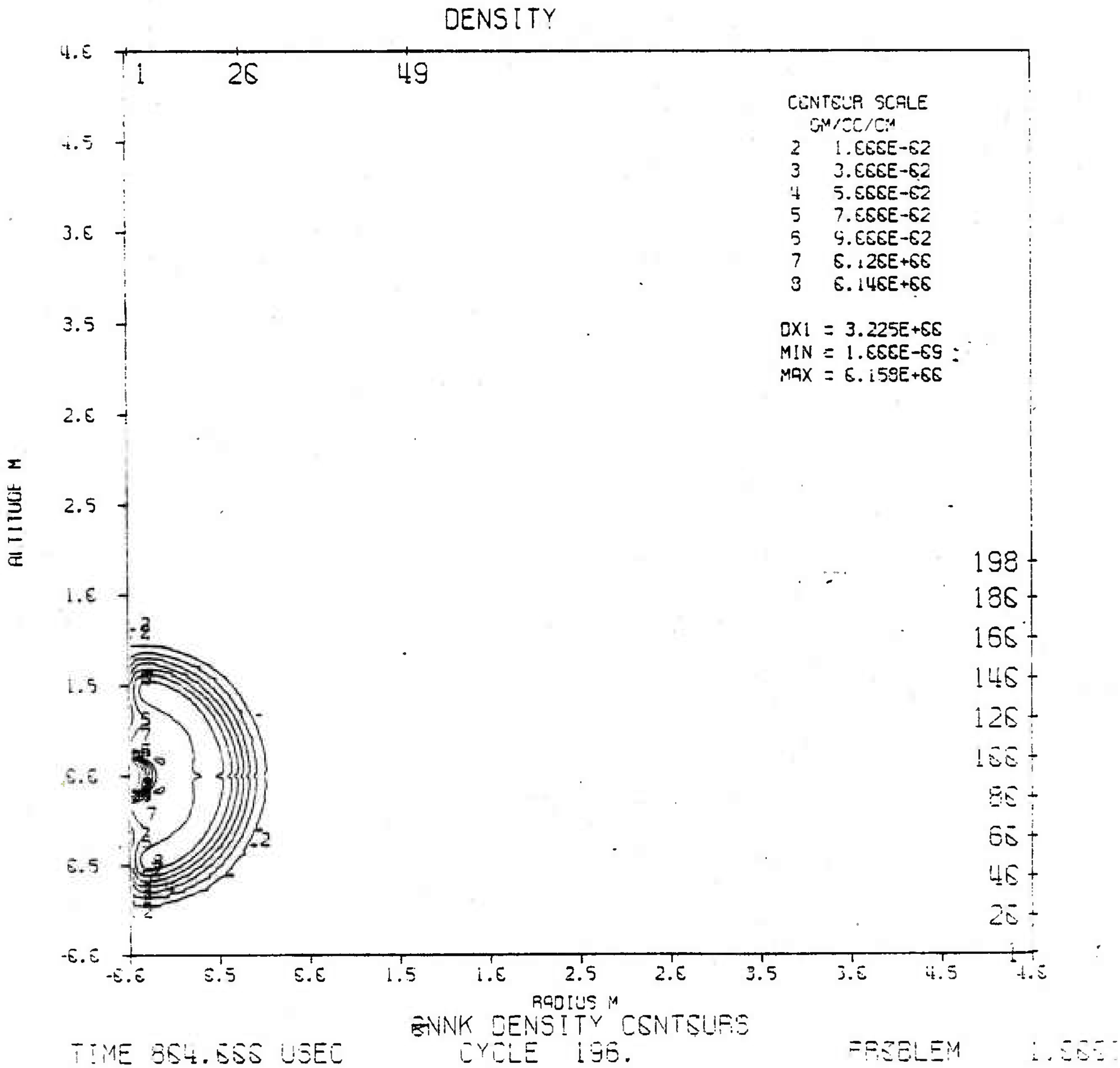



Figure 3-9. Density Contours of Second Expanding Aluminum Sphere at T = 8.14 x $10^{-6}$ sec.

# 4. CREATION AND UTILIZATION OF PROBLEM-DEPENDENT HULL LGO FILES

The development of HULL problems can be expedited by using the technique described below. As will be described, the technique is more efficient and significantly reduces problem development time by eliminating unnecessary file manipulations and compilations for a given HULL problem.

The job control stream used to create the LGO (absolute) file is very similar to that of an ordinary HULL execution. First, the HULL problem tape, TAPE4 (created via KEEL) is attached and the HULL library is made active. PLANK is then utilized to determine that the HULL source cards are to be used, and DYTHUL is invoked to generate the required source cards and write them on the SAIL file. FORTRAN compilation of the SAIL images is performed and the resulting LGO file is cataloged. This process is required for each different problem attempted, but needs to be performed only once per problem. Figure 4-1 depicts the jobstream to create a typical LGO file.

Utilization of the LGO file requires the attachment of TAPE4 (the HULL problem/dump tape). The LGO file is attached with the LFN of LGO. After PLANK reads the HULL problem tape, the command LGO begins execution/continuation of the problem. At the end of the execution EXTEND, TAPE4 is needed. Figure 4-2 illustrates the utilization of a typical LGO file.

In three (3) cases, this technique has increased the efficiency of a typical HULL run by 50 $\sim$ 70%. By avoiding file handling and compilation on each run, a lower time limit may be used in the job card. This results in significantly more rapid turnaround, thereby decreasing the amount of time required in problem development. In one test case, the problem was executed simultaneously by both the old and new techniques. The new technique allowed completion of the problem while the job utilizing the old technique remained in the input queue.

In Figure 4-2, the SAIL CARDS and the DYTHUL and ATTACH, OLD commands have been included in the jobstream. However, these cards can probably be removed without affecting the utilization of the HULL LGO file.

```
JOB CARD
ATTACH,TAPE4,HULLDUMPTAPE,ID=HULL,MR=0.
REQUEST,LGO,*PF.
ATTACH,OLD,HULL104CONVERT,ID=SMCSAI.
MAP,PART.
ATTACH,A,HULLIB104,ID=SMCSAI
LIBRARY,A.
PLANK.
DYTHUL.
FTN,I=SAIL,PL=100000,L=SAVE,OPT=2,LCM=I,R=3.
CATALOG,LGO,HULLLGO,ID=HULL.
7/8/9
SAIL CARDS
7/8/9
HULL CARDS
6/7/8/9
```

Figure 4-1. Jobstream to Create Problem-Dependent HULL LGO File

```
JOB CARD
ATTACH,TAPE4,HULLDUMPTAPE,ID=HULL,MR=0.
ATTACH,LGO,HULLLGO,ID=HULL.
ATTACH,OLD,HULL104CONVERT,ID=SMCSAI.
MAP,PART.
ATTACH,A,HULLIB104,ID=SMCSAI.
LIBRARY,A.
PLANK.
LDSET(PRESET=NGINDEF)
LGO.
EXTEND,TAPE4.
7/8/9
SAIL CARDS
7/8/9
HULL CARDS
6/7/8/9
```

Figure 4-2. Jobstream to Utilize Problem-Dependent HULL LGO File

## 5. DISCUSSION AND CONCLUSIONS

The results of this study show promise in using HULL as a tool in this area. But there are several problems which need to be pursued if interest in this application continues. It is unknown why the boundary separation problem which was so prevalent in the original problem does not exist in this one. This discrepancy seems to indicate that these two problems are treated differently during execution. It is difficult to see how the execution portion could discriminate between the different methods of problem generation, so it must be assumed that KEEL causes different flags to be set and then different routines to be used for the execution of each type of problem. The fact that a rezone occurred successfully on a non-reflective bottom boundary when an isothermal sphere was generated and would not do so with the previous solutions seems to point strongly to this possibility.

The fact that HULL does not use temperature output in calculating material properties raises a point of concern for a problem of this nature. In a realistic case, nearly 100% of the x-rays and a significant portion of the gamma rays from a low yield weapon would be deposited in an aluminum shell of the thickness used in this problem, causing the formation of a very dense and hot plasma. This plasma would probably behave more closely to an ideal gas than it would to a solid metal with strength and stress properties. It is felt that the spalling which takes place in the second case of this report might result from extremely high pressures acting on a cold metal, and could be realistic results, not a fluke in the code, (if nature could set up a problem such as this where there was temperature independence). Although the spalling of the metal may be insignificant due to the small amount involved, it would be interesting to see the results of this problem with the radiation deposition taken into account and the subsequent treatment of the aluminum as a near-ideal gas.

It is felt that when HULL was originally developed to simulate nuclear blasts, the value of $2 \times 10^{12}$ ergs/gram for the internal energy of the air in the isothermal sphere was probably an optimum number giving results in close agreement to nuclear blast test results. Since for this problem the internal energy had to be increased to $10^{16}$ and $10^{17}$ ergs/gram, the treatment of the isothermal sphere has departed from optimal performance. It is not known how HULL treats air at such high internal energies. It is felt, though, that this area could use improvement, and that a separate equation of state should be used for air in this problem. The temperatures of the air given by HULL at these high internal energies are based on specific heat values obtained at much lower temperatures. Therefore, the temperatures given may not be close to realistic values.

It is evident from these studies that HULL has its practical limitations and that one must be careful in using the results from HULL for a novel problem. The fact that the approximations in the diffusion limiter were not accurate enough to treat the previous expanding aluminum sphere shows that HULL has limitations. However, by solving the same problem using other options in HULL, the versatility of the code overcame some of these limitations. The underlying problem with HULL, as with most other hydrocodes, is that much care must be taken in evaluating the correctness of the results. The programs are capable of producing almost any results that are desired, by selecting the correct initial data. This requires the code user be very judicial in the use of the tool. Comparison with other calculations should be done whenever possible, and as experience is gained, the results will become more reliable. It is felt that HULL is still a viable code in this area. As HULL is considered for use in still other new areas, it should be tried and tested as much as possible. If one way does not work, then others should be tried. For only then will the full capabilities of HULL be discovered.

## DISTRIBUTION LIST

| No. of Copies | Organization |
|---|---|
| 12 | Commander<br>Defense Technical Info Center<br>ATTN: DDC-DDA<br>Cameron Station<br>Alexandria, VA 22314 |
| 1 | Commander<br>US Army Materiel Development and Readiness Command<br>ATTN: DRCDMD-ST<br>5001 Eisenhower Avenue<br>Alexandria, VA 22333 |
| 2 | Commander<br>US Army Armament Research and Development Command<br>ATTN: DRDAR-TSS<br>Dover, NJ 07801 |
| 1 | Commander<br>US Army Armament Materiel Readiness Command<br>ATTN: DRSAR-LEP-L, Tech Lib<br>Rock Island, IL 61299 |
| 1 | Director<br>US Army ARRADCOM<br>Benet Weapons Laboratory<br>ATTN: DRDAR-LCB-TL<br>Watervliet, NY 12189 |
| 1 | Commander<br>US Army Aviation Research and Development Command<br>ATTN: DRSAV-E<br>P.O. Box 209<br>St. Louis, MO 61366 |
| 1 | Director<br>US Army Air Mobility Research and Development Laboratory<br>Ames Research Center<br>Moffett Field, CA 94035 |
| 1 | Commander<br>US Army Communications Research and Development Command<br>ATTN: DRDCO-PPA-SA<br>Fort Monmouth, NJ 07703 |
| 1 | Commander<br>US Army Electronics Research and Development Command<br>Technical Support Activity<br>ATTN: DELSD-L<br>Fort Monmouth, NJ 07703 |
| 2 | Commander<br>US Army Missile Command<br>ATTN: DRSMI-R<br>DRSMI-YDL<br>Redstone Arsenal, AL 35809 |
| 1 | Commander<br>US Army Tank Automotive Research and Development Command<br>ATTN: DRDTA-UL<br>Warren, MI 48090 |
| 1 | Director<br>US Army TRADOC Systems Analysis Activity<br>ATTN: ATAA-SL, Tech Lib<br>White Sands Missile Range<br>NM 88002 |
| 1 | AFELM, The Rand Corporation<br>ATTN: Library-D<br>1700 Main Street<br>Santa Monica, CA 90406 |
| 1 | Computer Sciences Corporation<br>ATTN: Lewis P. Gaby<br>1400 San Mateo Blvd SE<br>Albuquerque, NM 87108 |

## DISTRIBUTION LIST

| No. of Copies | Organization |
|---|---|
| 1 | Orlando Technology, Inc.<br>ATTN: Daniel Matuska<br>P.O. Box 855<br>Shelimar, FL 32579 |
| 2 | Science Applications, Inc.<br>ATTN: Henry T. Smith<br>Kenneth H. Dent<br>2109 W. Clinton Ave, Suite 800<br>Huntsville, AL 35805 |

Aberdeen Proving Ground

Dir, USAMSAA
ATTN: DRXSY-D
DRXSY-MP, H. Cohen

Cdr, USATECOM
ATTN: DRSTE-TO-F

Dir, USACSL, Bldg. E3516
ATTN: DRDAR-CLB-PA

USER EVALUATION OF REPORT

Please take a few minutes to answer the questions below; tear out this sheet and return it to Director, US Army Ballistic Research Laboratory, ARRADCOM, ATTN: DRDAR-TSB, Aberdeen Proving Ground, Maryland 21005. Your comments will provide us with information for improving future reports.

1. BRL Report Number______________________________

2. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which report will be used.)

___________________________________________________

___________________________________________________

___________________________________________________

3. How, specifically, is the report being used? (Information source, design data or procedure, management procedure, source of ideas, etc.)______________________________

___________________________________________________

___________________________________________________

4. Has the information in this report led to any quantitative savings as far as man-hours/contract dollars saved, operating costs avoided, efficiencies achieved, etc.? If so, please elaborate.

___________________________________________________

___________________________________________________

5. General Comments (Indicate what you think should be changed to make this report and future reports of this type more responsive to your needs, more usable, improve readability, etc.)__________

___________________________________________________

___________________________________________________

___________________________________________________

6. If you would like to be contacted by the personnel who prepared this report to raise specific questions or discuss the topic, please fill in the following information.

Name:______________________________

Telephone Number:______________________________

Organization Address:______________________________

______________________________

______________________________